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(54) MULTI-LAYER VACUUM EVAPORATION DEPOSITION METHOD

(71) We, HITACHI, LTD., a Japanese Company of 1-5-1 Marunouchi, Chiyoda-ku, Tokyo, Japan and HITACHI DENSHI KABUSHIKI KAISHA, a Japanese Company of 23-2 1-chome, Kandasudacho, Chiyoda-ku, Tokyo, Japan, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The present invention relates to a multi-layer masking evaporation deposition method using a plurality of evaporation sources.

The technique of forming patterns by using multi-layered deposited films is utilized in various fields, e.g. for production of integrated circuits.

For example, when a CR-Au wiring pattern is to be formed in an integrated circuit or the like the following steps may be used:-

i) A Cr film is deposited on a substrate by vacuum evaporation-deposition.

ii) An Au film is applied over the Cr film by electroplating or evaporation deposition.

iii) An Au pattern is formed by photolithography.

iv) The Cr layer is processed by further photolithography so that a CR pattern larger than the Au pattern is formed.

The lower (Cr) layer pattern is made larger than the upper (Au) layer pattern to prevent stripping of the layers during various post-treatments conducted after wiring, such as ultrasonic cleaning. For example, with such a two-layer film, if the Au film is etched and the lower Cr film is then etched using the resulting Au film pattern as a mask, the etching solution intrudes and etches the Cr film even below the Au film, As a result, the edge of the Au film has no Cr film beneath it and is caused to peel upwardly. If ultrasonic cleaning is carried out in this state, the Au film is easily stripped. To avoid this in the conventional method the Au etching step and the Cr etching step are indepensable in addition to the Cr - Au evaporation deposition step, the three steps being necessary for the wiring of Cr-Au conductors.

Thus the conventional method is time-consuming since much time is required for carrying out these steps and the rate of production is low. The conventional method also has problems concerning the difficulty of preserving Au and Cr etching solutions and photoresist treating agents such as developers and resist strippers, and also of waste water treatment.

A known method for eliminating the wet etching steps uses a mask which is formed on a substrate by evaporation deposition, to form a pattern. For example, this method is disclosed in "Handbook of Thin Film Technology, pages 7-3 to 7-10" by L. Maissel and R. Glang, published by McGraw Hill Book Company in 1970.

In another known method, a plurality of substrates are disposed around a rotary substrate holder and evaporation films are deposited on the substrates from a single evaporation source or a plurality of suitably located evaporation sources. This technique is disclosed, for example, in the specification of British Patent Application No. 11476/77 (Serial No. 1, 532, 183).

In each of these known methods, in order to make the size of the upper layer pattern smaller than the size of the lower layer pattern, it is necessary to perform evaporation deposition twice using different masks, which necessitates the troublesome step of registering the two masks correctly with each other.

The present invention uses only vacuum evaporation deposition, and formation of a pattern is accomplished by a mask evaporation deposition method. Furthermore the method of the invention permits one to make the size of one evaporation-deposited film pattern smaller than the size of another.

According to the present invention there is provided:-

1) A multi-layer vacuum evaporation-deposition method comprising;

a) providing at least one substrate with a mask fast therewith said mask having a masking edge which limits the region of the substrate on which deposition occurs the masking edge being spaced from the substrate,

b) rotating said substrate and mask about an axis spaced from the substrate while depositing a film on the substrate by evaporation-deposition from a source;

c) rotating said substrate and mask about said axis while depositing a film on the substrate through the mask by evaporation deposition from a further source, wherein the two sources are so positioned that a first one of them is within a cone defined by rotation about said axis of a line joining the second source to the point of the path traced out by the rotating substrate which is remotest from said second source and not masked therefrom, and said second source is outside a cone defined by rotation about said axis of a line joining said first source to the point of the path traced out by the rotating substrate which is nearest to said first source and not masked therefrom and wherein said mask and sources are so arranged that the films deposited on the or a substrate from the two sources are in a wholly or partially mutually overlying relationship.

In defining the two cones, it has been assumed that the sources are points, this is generally a good approximation. Strictly, the generating lines extending from the first and second sources should extend from the extremities of the sources which are respectively furthest from and closest to the relevant parts of the substrate path, but this does not make a substantial difference.

Some embodiments of the present invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 is a diagrammatic illustration of one embodiment of the present invention.

Figures 2A and 2B are diagrams illustrating in detail a part of Figure 1.

Figure 3 is a diagrammatic illustration of a second embodiment of the present invention.

Figure 4 is a sectional view showing a multi-layer film obtained according to the method of the present invention.

Figure 5 is a schematic representation of an apparatus for use in working the method of the present invention.

Figure 6 is a sectional view illustrating another multi-layer film obtained according to the method of the present invention.

Corresponding parts in different figures bear the same reference characters.

In the embodiment shown in Figure 1 a substrate S and an evaporation deposition mask M are fixed together and they are attached to a rotary substrate holder (not shown) and rotated about the central rotation axis 0-0' of the rotary substrate holder. A first evaporation source P is located at a distance L from the axis 0-0', and a second evaporation source Q is located so that its distance from the axis 0-0' (in this case zero) is smaller than the distance L. The paraxial distance between the substrate holder and the second evaporation source is equal to the paraxial distance between the substrate holder and the first evaporation source.

While rotating the substrate holder, a first material for deposition, for example Cr. is evaporated from the first evaporation source P. The pattern fringe of the evaporation deposition mask which has a thickness of about 50 to about 100μ) will generally be rounded as shown in Figure 2A as a result of its method of manufacture and there is a narrow gap (about 10μ) between the masking edge of the mask and substrate. Consequently the evaporated substance penetrates a short distance beneath the mask (about 5μ).

The source P is spaced from the axis 0-0', and this spacing increases the depth of penetration of the substance (Cr) from the source P, as indicated by the solid lines in Figure 1. These solid lines indicate the maximum width of a film pattern formed by evaporation deposition. In Figures 2A and 2B reference numeral 2 represents a Cr film thus formed. Material from the source Q (which is not spaced from the axis) can penetrate less far.

In order to enhance these differential penetration effects an appropriate spacer 4 may be disposed between the substrate and the mask as shown in Figure 2B.

After deposition of the first substance (Cr) from source P, a second substance for example Au, is evaporated from the second evaporation source Q. The maximum pattern width of the evaporation-deposited Au film is narrower than that of the Cr film

produced by source P, as indicated by broken lines in the drawing. In Figures 2A and 2B reference numeral 3 represents an Au film thus formed. With the sources P and Q arranged as described above, the pattern width of the Cr film formed by evaporation from the first source P can always be made larger than the pattern width of the Au film formed by evaporation from the second source Q.

In the Figure 1 embodiment, the two sources P and Q are in the same radial plane and source Q is on the axis 0-0'. These conditions are not necessary if the sources P, Q are in the same radial plane the desired effect can be attained if source Q is radially inward of source P. Furthermore it is not necessary for the sources to be in the same radial plane so long as the second source Q is father from the substrate holder than is the point R of intersection with the axis 0-0' of a line connecting the first source P to the remotest point from the source P of the substrate S.

The positioning of sources P and Q will now be discussed further with reference to the Figure 3 embodiment. The second source Q is located inside the cone defined by rotation about the axis 0-0' of a line connecting the first source P to the end F remotest therefrom of the substrate in the most remote position of the substrate. The apex of this cone is the point R of intersection of the generating line with the axis 0-0'. The first source is located outside the cone defined by rotation about the axis 0-0' of a line connecting the second source Q to the end N nearest thereto of the substrate in the nearest position of the substrate. With this positioning of the sources, the desired differential penetration effects can be obtained.

As will be apparent from the foregoing description by the method of the present invention, a two layer film having a sectional structure as shown in Figure 4 can be formed by using one mask and two evaporation sources. Accordingly, the wet process steps (such as treatment with chemical solutions) need not be performed at all. Therefore the number of steps can be greatly reduced and maintenance of chemical solutions and treatment of waste water become unnecessary.

Furthermore the present invention can be used to make a multi-layer film having three of more layers in which the pattern width of succeeding layers is gradually reduced. In this case three or more evaporation sources are used, arranged so that the above-mentioned positional relationship holds for every two adjacent sources.

The positioning of the sources with respect to the substrate will now be described with reference to specific examples. Figure 5 is a schematic diagram of an apparatus for working the method of the present invenion which is suitable for these specific examples.

A substrate 52 is set on a rotary substrate holder 51 together with a mask, and the substrate 52 is rotated at a rate of 5 to 45 rotations per minute about its axis i - i'. Of course, the intended object can be attained even if the substrate 52 is rotated intermittently. Examples of suitable sets of dimensions are shown in Table 1. In this Table, A is the diameter of the rotary substrate holder 51; B is the distance between the centres of the outermost substrates; C is the distance between the first evaporation source 53 and the central rotation axis i-i'; D is the distance between the axis i - i' and the second evaporation source 54; and E is the distance between the radial plane including both the evaporation sources and the plane of the substrates.

Table 1

Distance	*Example (I)*	*Example (II)*	*Example (III)*
A	270	270	270
B	204	204	204
C	60	85	100
D	0	40	60
E	160	160	160

units: m × 10^{-3}

In example (I), it is mainly intended to diminish the direction dependency of the difference between the width of a pattern formed by evaporation from the first evaporation source 53 and the width of a pattern formed by evaporation from the second evaporation source 54. The diameter A of the rotary substate holder 51 is set at 270 mm, the distance B between the centres of the outermost substrates (or the diameter of the path traced by the radially outermost substrate) is set at 204 mm, the distance C between the

central rotation axis i - i' and the first evaporation source 53 is set at 60 mm, the distance D between the central rotation axis i - i' and the second evaporation source 54 is set at 0 mm (i.e. the second evaporation source 54 is located on the axis i - i'), and the distance E between the plane of the sources and the plane of the substrates 52 is set at 160 mm. The rotary substrate holder 51 is rotated at 20 rotations per minute. Firstly, Cr is evaporated from the first evaporation source 53, and secondly Au is evaporated from the second evaporation source to deposit a Cr-Au two-layer film. The evaporation deposition is carried out while the substrate is in close contact with a Mo evaporation mask having apertures of a predetermined pattern. As a result, there is obtained an evaporation-deposited multi-layer film having a sectional structure as shown in Figure 4, with a larger Cr pattern 2 and a smaller Au pattern 3. With apparatus dimensioned according to Example (I), the differences between the widths of the two patterns on both the right and the left sides can be very small, or even zero so that the Au pattern is completely within the boundaries of the Cr pattern.

In example (II), the mask evaporation is carried out in the same manner as described in Example (I) except that the dimensions of the apparatus are changed as indicated in Table 1. With these dimensions the thickness of the layer formed by evaporation from the first evaporation source 53 (Cr layer in this Example) can be made remarkably uniform.

The dimensions of Example (III) from both sources allow great uniformity of thickness of films from both sources. The fluctuation in thickness of the layer formed by the first source 53 is so small as to be practically negligable and the thickness distribution of the layer formed by evaporation from the second source 54 is so improved that the ratio of the maximum thickness of the minimum thickness is less than 1.5.

In the present invention, when two evaporation sources are located on the same horizontal radial plane as shown in Figure 5 as will be apparent from the principle of the present invention, the intended object can be attained if the requirement of C>D is satisfied. However, from the viewpoing of practicality and safety, if is preferred that the respective distances A to E be arranged as follows.

The distances A, B, C and E are restricted by the dimensions of the vacuum apparatus, and when the respective distances are set within ranges satisfying the requirement of the present invention, because of limitations imposed on the thickness distribution and the apparatus mechanisms such as shutter mechanism and from the viewpoint of the film control, it is difficult to reduce the value of E below 0.2B. Furthermore, because of the limitation on the pattern width difference between the two layers, it is difficult to increase the value E beyond about 5B. Thus E is generally within the following range:

$$E = 0.2B \text{ to } 5B$$

The operational efficiency is reduced when the first evaporation source is located far radially outward of the substrate holder. For this reason and because of the film control, it is difficult to increase the value C beyond 1.5B. From the viewpoint of the pattern width difference, a suitable minimum value of the difference between C and D (C-D) is 20 mm and if the case of D = 0 is allowed, the value C is generally within the following range:

$$C = 20 \text{ mm to } 1.5B$$

The value D should naturally be limited by the above-mentioned value of C and may be adjusted within the following range:

$$D = 0 \text{ mm to } (1.5B - 20 \text{ mm})$$

When the distance between the second evaporation source 54 and the surface of the substrate 52 is different from the distance between the first evaporation source 53 and the surface of the substrate 52, the value D is adjusted within the following range:

$$D = 0 \text{ mm to } \frac{E'}{E}(1.5B - 20 \text{ mm})$$

in which E and E' are the distances of the substrate 52 from the first and second evaporation sources respectively.

It is further necessary that the second evaporation source should be further from the substrate than is the point R of intersection of the line connecting the first evaporation source 53 to the end remotest therefrom of the substrate 52 and the central rotation axis i - i' 51. In this case, the maximum value of E' is about 10B.

The respective distances are adjusted within the above-mentioned ranges.

In the foregoing Examples (I) and (III), C and A are arranged in optimum ranges while setting B and E at 204 mm and 160 mm respectively. In such case, C is in the range of from about 0.3 B to about 0.5B and D is in the range of from 0 mm to 0.3B. These optimum ranges are determined depending on such factors as the film control and

the difference of the pattern width between the first evaporation deposited layer and the second evaporation deposited layer.

The number of rotations of the substrate holder is set in dependence on the intended thickness of the film and the evaporation deposition speed. From the viewpoint of the uniformity of the film thickness, the substrate should be rotated at least 5 times and in order to obtain a good uniformity in film thickness in the edge portion of the pattern and the pattern difference in the edge portion of the pattern and the pattern difference in the two-layer film, it is very desirable to rotate the substate holder at least 10 times.

In the foregoing description it has been assumed that it is desired to produce a lower layer which is at least as wide as the upper layer, as is usually desired when producing Cr-Au, Ni Cr-Au and Cr-Cu conductor patterns. However, it is sometimes required that the pattern width of the upper layer should be made larger than that of the lower layer. For example, this is required when a conductor or photo-conductor 2 is first formed on the substrate S (such as glass or Si) and a protective or insulating layer 3 is then formed on the entire surface as shown in Figure 6. The present invention can be applied also to production of such multi-layer films by reversing the order of use of the evaporation sources. By this means a structure as shown in Figure 6 can be obtained by a single evaporation step.

Thus by a method according to an embodiment of the invention a multi-layer pattern can be produced in less steps than are required by 'wet' chemical methods, and without the problems associated with storage and disposal of chemicals. Furthermore by using an embodiment of the invention it is possible to produce, using a single mask a multi-layer pattern with a desired relationship between the sizes of the layers.

WHAT WE CLAIM IS:-

1. A multi-layer vacuum evaporation-deposition method comprising:-

a) providing at least one substrate with a mask fast therewith said mask having a masking edge which limits the region of the substrate on which deposition occurs, the masking edge spaced from the substrate;

b) rotating said substrate and mask about an axis spaced from the substrate while depositing a film on the substrate by evaporation-deposition from a source;

c) rotating said substrate and mask about said axis while depositing a film on the substrate through the mask by evaporation-deposition from a further source, wherein the two sources are so positioned that a first one of them is within a cone defined by rotation about said axis of a line joining the second source to the point of the path traced out by the rotating substrate which is remotest from said second source and not masked therefrom and said second source is outside a cone defined by rotation about said axis of a line joining said first source to the point of the path traced out by the rotating substrate which is nearest to said first source and not masked therefrom

2. A method according to claim 1 wherein said mask is arranged and adapted to produce a multi-layer film in which no layer extends radially beyond a layer of larger or equal size.

3. A method according to claim 1 or claim 2 including the steps of mounting the or each substrate on a substrate holder which is rotated to perform steps (b) and (c).

4. A method according to any one of claims 1 to 3 wherein a spacer is inserted between said substrate and said mask.

5. A method according to any of the preceding claims wherein evaporation deposition from said second evaporation source is carried out prior to evaporation deposition from said first evaporation source.

6. A method according to any one of claims 1 to 5 wherein said two evaporation sources are substantially in a plane parallel to a plane including the surface of the substrate onto which deposition occurs.

7. A method according to claim 6 wherein the distance between said planes is in the range of 0.2 to 5 times the diameter of the path described by the radially outermost substrate.

8. A method according to claim 6 or claim 7 wherein the distance between said second evaporation source and said axis is in the range from 20 mm to 1.5 times the distance between said two planes.

9. A multi layer vacuum evaporation deposition method substantially as any of the Embodiments herein described with reference to the accompanying drawings.

10. A substrate which has been subjected to treatment by a method according to any one of the preceding claims.

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FIG. 1

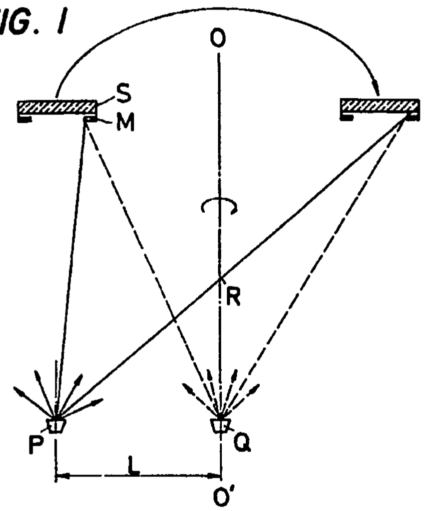

FIG. 2A

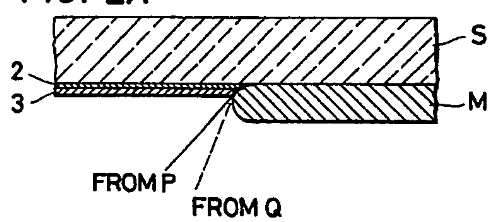

FIG. 2B

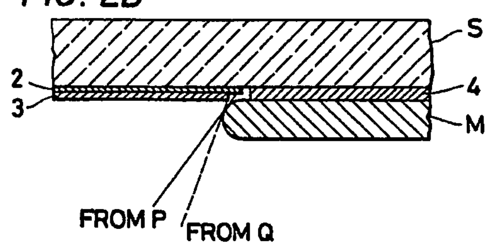

FIG. 3

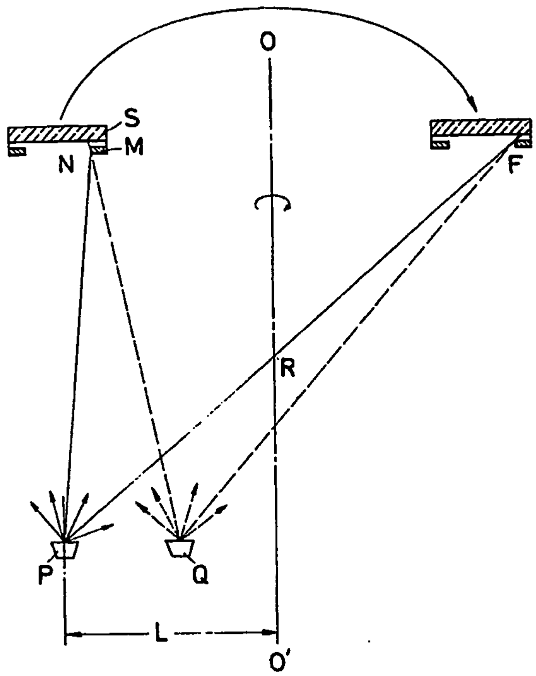

FIG. 4

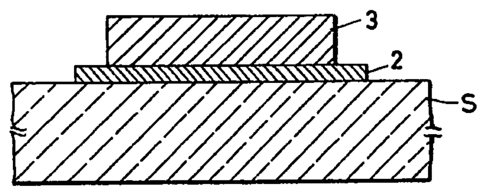

FIG. 5

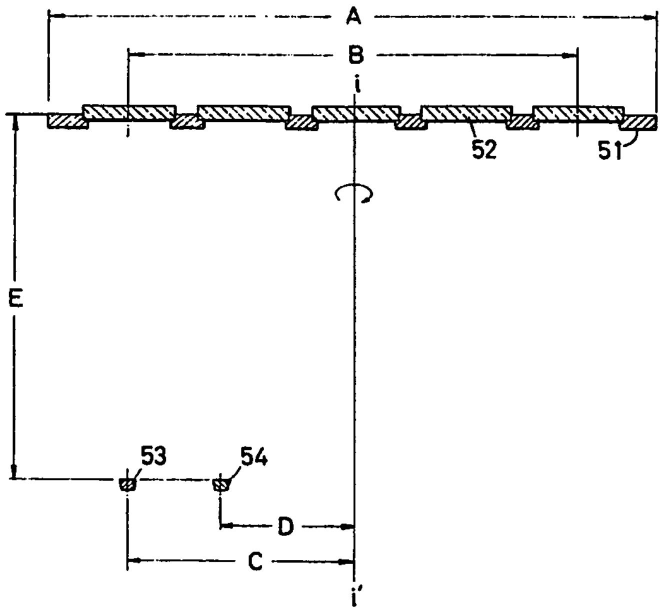

FIG. 6